THE PROBLEM OF AGRICULTURAL ECOLOGY.

By G. AZZI.

[International Institute of Agriculture, Rome, Italy, Apr. 5, 1922.]

"We must come universally to the practice of producing seed adapted not only to the region, but to the individual locality."—C. S. Brand, United States Department of Agriculture.

Too little attention has been paid up to the present to the study of environment in agriculture. As yield is the result of a compromise between specific productivity and resistance to the most adverse phenomena, will it be possible to come to any conclusion relative to data for sowing, choice of variety, etc., when one of the terms of the compromise is absolutely or almost completely disregarded? It will be impossible, just as it is impossible for a tailor to make a suit for a man whom he has never seen and whose measure he has never taken.

By agricultural ecology we mean the study of the action of the different meteorological factors (in the atmosphere and soil) and the discovery of the extent to which it expresses itself with relation to the plant as regards the development and the yield. A more exact representation of environment will be of great use to the agriculturist and help him in all his endeavors leading to a better adaptation of culture to climate and soil. Researches conducted and data worked out by the method proposd aim at establishing for each plant cultivated (in the different points of its area of distribution) the genetic factors which rule its behavior in relation to environmental conditions and the exterior agents or group of agents which display the greatest influence on yield revealing the characters of susceptibility or resistance determined by the genetic factors.

Observations with reference to the relations between environmental factors and plant growth should be taken during the critical periods after determination of the optimum date for sowing. Frequency and intensity of adverse phenomena in connection with the critical periods will determine the degree of resistance that is necessary to overcome unfavorable conditions and produce a good harvest. Such determinations are not only useful, but absolutely necessary, to carry out plant breeding on a rational basis.

Collection of data.—To obtain meteorological figures and biological data for comparison, observations on meteorological factors and biological researches will be conducted on parallel lines in the same place.

Elaboration of data.—Leading to the determination of (1) critical periods; (2) frequency and intensity of the different meteorological phenomena; (3) phenological means.

Points 1–3 enable one exact biometeorological balance to be established.

Application of data (worked out as above).—Leading to the following results: (1) Choice of the variety most suitable to the given conditions; (2) best dates (5) for sowing; (3) most suitable cultural operations to escape unfavorable climatic conditions and best times for carrying them out; (4) a practical knowledge of environment for the plant-breeder to enable him to obtain the type (3) most likely to succeed under actual meteorological conditions.

The fact that the negative action of the meteorological factors has a decided influence yearly on the decrease in crop yield has for a very long time past attracted the attention of students and practical workers. In the year 286 B. C. Theophrastus asserted that *annus fructificat non tellus*, and was followed by Columella, Vergil, Varro, and a hundred others during the Greek-Roman period, the middle age, and up to recent times. On the other hand, there is no agricultural country where the nature phraseology does not include proverbial sayings with special reference to the relationship between the critical periods of plant growth and weather.

At the present time observations are being made in connection with agricultural meteorological work almost everywhere. Before the war and revolution there was in Russia an excellent agricultural meteorological service, organized by Prof. P. I. Brounov, the founder of agricultural meteorology, and periodical publications on the subject were issued.

Many countries publish periodical information on weather and crops, and a considerable quantity of information has been accumulated, but without system or coordination. It is not really sufficient to make parallel observations on the development of a plant and meteorological factors unless some method is followed which will allow the utilization of the data thus accumulated in connection with the improvement of agriculture and the practical solution of the problems closely connected with agricultural meteorology.

Following up the works of preceding authors (Brounov, Warren, Smith, Gauer) and utilizing the present writer's own theory, I have combined all the elements and data into a new system of research.

For this purpose the following points, must be established: (1) The critical period; (2) phenoscopic averages; (3) the percentages of probability of the various meteorological phenomena for each 10-day period during the season of growth; (4) decrease of the yield caused by various unfavorable conditions (this decrease measures the intensity of action of the different unfavorable factors).

GENERAL RULES TO BE OBSERVED WHEN MAKING BIO-METEOROLOGICAL OBSERVATIONS.

Critical period.—This, for instance, as regards rain, is the term applied to the short interval of vegetative growth during which the plant absolutely requires a certain minimum of atmospheric precipitation.

If during the critical period the total rainfall is less than the minimum needed for the normal development of the plant, the crop will be small, even if there is an abundance of rain throughout the rest of the vegetative period. In the same way, should the requirements of the plant be satisfied during the critical period, the crop will be large, even if the rainfall is relatively scanty and badly distributed throughout the remainder of the vegetative period.

One of the critical periods of cereals falls within the 20 days before heading, and if at this time the rain is not sufficient to keep the soil moisture above a certain limit the grain crop will be seriously reduced.

This is, in fact, the moment when the plant is most active, and produces the vast amounts of plastic substances necessary for the formation and growth of the caryopses; during this process it consumes a large quantity of water. Between the heading stage and ripening there is on an average an interval of 40 days, and during these 40 days all the growth processes are abridged, the later stages following one another rapidly—flowering, setting, and the development and ripening of the caryopses.

It is therefore indispensable, in order to insure a good wheat crop, that the rainfall should be abundant during one or both of the 10-day periods before heading, so as to supply the plant with the moisture necessary for the rapid and important growth operations.

What has been said regarding rainfall holds good in the case of all the other meteorological factors and phenomena.

A simple inspection of yield, figures, and meteorological values, reported for the different stages of growth, will occasionally reveal at once the existence of the "critical period." But as the different factors act contemporaneously and the problems of interaction become more complicated, experimental control in every case will be necessary to isolate the action of a single factor.

Following the lines laid down, experiments were carried out by the writer last year with four varieties of wheat cultivated in pots in conditions rendering it possible to vary artificially the degree of humidity during the 20-day period before heading.

Results confirm fully the existence of critical periods. With the increase of irrigation there was a corresponding increase in yield (weight of grain per ear in centigrams).

The statistical method and formulas have been proposed (and largely applied) for determination of the corelation between yield and meteorological values, but this method should not be overestimated. In a general way mathematical formulas can not be used to discover or determine the degree of correlation between meteorological values and yield.

Diminution of product caused by a given rainfall over the optimum is not the same as the diminution caused by equal rainfall under the optimum. As the deviations have not a corresponding relationship to the optimum (as well as to the mean), the application of formulas (of correlation and regression) based on the study of deviations may lead to erroneous conclusions.

In some countries agricultural meteorology has fallen partially, at any rate, into the hands of statisticians and mathematicians, very fine formulas, graphs, and equations have been worked out, while the application of correlation and regression coefficients became the *leit motif* in agrometeorological researches.

It is to be feared that this work, important as it may be from certain points of view, will not always lead to practical results.

Phenoscopic averages.—In every district it is necessary to find out the average date of each stage of growth. Thus, in the case of wheat, the average date of germination, heading, flowering, etc., must be determined.

The critical periods, as regards the various meteorological phenomena and factors, always coincide with some stage of growth (heading, flowering, etc.), the mean phenoscopic data thus enable us also to fix the date of the critical periods.

Example.—At station A, the average date of the heading of wheat is May 10. The critical period of the wheat from the point of view of rainfall (soil moisture) falls, however, between April 20 and May 10—that is to say, in the 20 days before the ears develop.

Percentage probability of the different meteorological phenomea.—In 1910, in the district of Bologna, no rain fell during the two periods of 10 days preceding the heading of the wheat, which took place that year on May 15, and the crop turned out far below the average, being only 12 quintals per hectare.

During the first half of April, however, there had been abundant rain. By sowing sooner, or using an earlier-ripening variety, it would have been possible to alter the date of the heading phase to April 25–30, so as to make the critical period for moisture coincide with more favorable weather conditions.

In order to do this it would, however, be necessary to know in October what the weather is to be in the spring. The weather can only be forecast with certainty for 24 or, at most, 48 hours. *Thus crops can not be adapted to the weather.*

But if it is impossible to foresee in the autumn the atmospheric conditions that will prevail at Bologna and Sciacca (Sicily) during the second half of April, one thing is very certain—viz.; that drought in the second half of April is a much more probable and frequent occurrence at Sciacca than at Bologna.

If, therefore, it is not possible to adapt crops to the weather of the year, they can be adapted to the average climatic conditions, which can be shown by the percentages of probability—probability of frost, drought, storms, fogs, etc.

Brounov has already suggested that a 10 days' period be called "dry" if the total atmospheric precipitation does not exceed 5 mm., but if this definition can perhaps be accepted by the climatologist it is of very relative value to the agriculturist.

The important point is not the sum total of the atmospheric precipitation, but the amount of water actually at the disposal of the plant which is represented, at least to some extent, by the soil moisture. The latter, however, even when the amount of rain is equal varies within very large limits according to thermic, agrogeological, topographical conditions, and the like. Therefore, in speaking of drought, we must adopt the ecological criterion and refer "to the complex of values and environmental relations producing a deficiency of the water required by a given cultivated plant."

This is a question for the biologist and comes within the province of plant physiology.

When once the meterological values resulting in "dryness" have been determined on the basis of a thorough knowledge of the local agrogeological conditions, the probable occurrence, or the frequency of these values, can easily be established for periods of 10 days.

By calculating for a certain district and for a long series of years (at least 20), the number of times a particular 10 days' period has been "dry" and expressing the results thus obtained as percentages, the figures will give the probability of drought during that period of 10 days.

If we suppose that at station A, the second decade in July is dry 15 times in 20 years, we can say that the probability of drought during that period at A is 75 per cent.

What has been said regarding drought also applies to all other meteorological factors or phenomena.

The determination of the decrease in yield due to different unfavorable meteorological phenomena.—Example.—Drought and wheat at station A:

(*a*) Average grain crop in years when drought has not *prevailed* during the 20 days previous to heading.

(*b*) Average grain crop in years when drought has *prevailed* during the 20 days before heading.

(*c*) The difference between the two crops (*a* and *b*) gives us the mean decrease in yield due to the drought. It may be assumed that this difference amounts to 5 quintals.

The comparative examination of the phenoscopic factors (the average date of heading) and of the percentage of the probability of drought permit the determination of the frequency of drought during the critical period at station A.

Suppose that the probability of drought during the two decades (periods of 10 days) before heading is 20 per cent (drought occurring in one year out of five. With a loss of 5 quintals per hectare owing to want of rain (as assumed) and with a 20 per cent probability of drought (one year in five), the annual reduction in yield caused by want of rain would amount on an average to 1 quintal per hectare.

Biometeorological balance.—By adopting this method it would be possible to construct a mathematically correct balance for every cultivated plant, for the different parts of its area of distribution.

Example: In the district of X the drought caused an average decrease of 2 quintals of grain per hectare, the frosts were responsible for a loss of 0.10 quintals, and lodging for a decrease of 0.50 quintal. In *X, drought was the meteorological factor most injurious to wheat.*

In the district of Y, 3 quintals were lost owing to lodging, 1 quintal from frosts, and 0.50 quintal through drought. Therefore, *in Y, lodging* (produced by heavy showers accompanied by wind) *is the most injurious factor.*

In this way it is possible to obtain a sure guide as to the means to be adopted in each district in order to limit the damage caused by unfavorable weather conditions. What are these means?

The manner in which a knowledge of the critical periods, of the decrease in yield due to various meteorological factors, the phenoscopic averages, and the percentage of probability and frequency of the different meteorological phenomena would make it possible to increase the yield by the progressively better adaptation of crops to climatic conditions.

Once the *chief cause* of the low returns is determined, there are three ways of finding a remedy.

(1) By altering the time of the growth stage for which the critical period has been discovered in such a way as to make this period coincide with more favorable weather conditions.

Example: The average date at which the variety of wheat heads at station A is May 18, while, on the other hand, the probability of drought during the last 10 days of April and the first 10 days of May (critical period) is 70 and 75 per cent, respectively. This is the reason of the somewhat low yield. In the first and second 10 days of April, however, the probability of drought falls to 10 and 15 per cent, respectively. Therefore by sowing or using an earlier ripening type of wheat, which would head between April 20 and 25, it would be possible to escape, at all events to some extent, the injurious effects of the want of rain.

(2) By artificially altering the meteorological conditions during the critical period—for instance, by irrigating in districts subject to drought. In such a case the knowledge of the critical period would enable much water and labor to be saved, as the operation could be confined to the time of actual and greatest need.

(3) Plant breeding to obtain resistant varieties to the most adverse meteorological conditions. This is of the most effective means of checking atmospheric influence. In this connection it is necessary to study the matter more in detail because of the great disappointments met with by some breeders in trying to export varieties to countries far from the original region and with different climates.

Most of the cultivated wheat varieties are from the genetic point of view more or less mixed types (populations) differing physiologically and morphologically in their fixed characters. The choice of these forms by pure-line breeding must be the first endeavor of the breeder with a view to obtaining later further improved types by hybridization and selection. On the other hand, good results can be obtained and breeds of consistent stability assured by the simple pure-lines selection.

As a result of this first trial some pure lines will be obtained, each one derived from a single parent plant and in all probability with very constant characters.

Among these, lines with high resistance to the most adverse meteorological condition and most adapted to particular conditions of a given locality should be chosen and the best date of sowing determined. Once this work is achieved no further improvement is possible unless mutations occur, which, however, is very seldom the case.

For further improvement it will be necessary to fall back on hybridization.

In the A station, exposed to drought, suppose a pure-line selection is obtained distinguished by its high degree of resistance. But as generally increased hardiness (rusticity) is followed by lowering of specific yielding capacity, the new drought-resistant line will give a sure and constant yield (also in an unfavorable season), but somewhat low. In this case to get a higher yield it is necessary as already stated to proceed to hybridization.

Owing to the individuality and independence of characters (low and high yielding capacity, high or low degree of resistance to drought, etc.), as shown by phenomena of division and recombination of characters, it is possible to combine by crossing in one type two characters from two different parents (types).

In the case under consideration the local variety very resistant but low yielding will be crossed with another variety nonresistant to drought but showing a good yield.

Before crossing, the exotic variety should be acclimatized and undergo pure-line selection so as to control purity and become familiar with the specific characters. After hybridization the subsequent work of choice and isolation of forms should be carried on carefully and continuously with the idea of choosing between the numerous forms the form which combine the two characters "high yielding capacity" and "resistance" in the most favorable proportion with elimination of negative characters.

In Sweden, where low temperature is the most dangerous meteorological factor, excellent wheat varieties were produced very resistant to cold and giving a good yield by crossing the local resistant variety with the English Square-head, a good yielder. The work of hybridization and selection conducted by scientific methods for over 30 years has given the variety "Pansar," which yields 67 per cent more grain than the indigenous wheat. Pansar was obtained by crossing *Granadier* (a pure line, acclimatized from Square-head) with *Kotte* (a pure line from the indigenous Swedish wheat).

The use of the method suggested and described would lead to the following results:

(1) It would show which among the many varieties of a cultivated species, such as wheat, is the most suitable for a given district. The tendency to use and introduce over too-wide areas and in surroundings somewhat different from their place of origin the new products obtained by selection, or crossing combined with selection, has already led to many serious disappointments.

(2) It would show the best date for sowing with the view of making the critical periods coincide with the most favorable weather conditions without leaving out of account the length of the solar day, which exercises so great an effect upon the life of the cultivated plant.

(3) It would demonstrate the most suitable cultural operations and the best time to carry them out with the object of controlling the negative action of unfavorable meteorological factors or phenomena.

(4) It would guide the plant breeder in his efforts to unite in a single individual and in the best proportions for obtaining the maximum yield the character of "specific productivity" and of "resistance to the most injurious meteorological phenomena."

In the results obtained by the work of environmental analysis and of ecological synthesis, which has been extended to all parts of the area of present and possible cultivation, we should have the data necessary for the construction of the common basis, the fundamental plan of collaboration, on which should be founded the labors of the plant breeders of every country. From these data they will learn the requirements of the different climatic zones of wheat (and of other species of plants), and will be able to correlate their labors in a single well-devised effort to attain clearly defined aims.

The amount of risk from unfavorable weather conditions depends naturally on the intensity and frequency of such phenomena and on the possibility of adapting crops to climate in the way we have described. The atmospheric surroundings of a region then lose something of their instability and acquire a fixed character almost like the soil and the topographical conditions. It is possible and necessary to take them into account in judging a farm.

Paragraphs 1–4 describe the long and careful work of choosing suitable crops and adapting them to the climate. This work can not fail to have definite results, even if they are only partial, given the large scale on which it is applied and the high figures involved. The gist of the whole matter is, that the risk of loss (owing to unfavorable weather conditions) is reduced, and larger returns obtained without extra expense, which means a real increase in the value of the capital.

The problems of agricultural meteorology may, however, be subdivided into two main categories:

(1) *Weather forecasts*, which are in the province of the meteorologist, although they may be useful to the agriculturist in adapting his crops to the weather (defense against frost, etc.).

(2) *Agricultural climatology* (in a wider sense Agricultural Ecology), which aims at adapting crops to climate, as is shown by studying the method we have suggested. It is quite distinct from pure meteorology and has a place as a separate branch in the group of biological sciences which are applied to agriculture, having many interesting points of connection with genetics and rural economy.

AGRICULTURAL CLIMATOLOGY OF AUSTRALIA.

There appeared in the *Quarterly Journal of the Royal Meteorological Society*, October, 1920,[1] a very complete and interesting paper by Dr. Griffith Taylor, associate professor of geography in Sydney University, dealing with the climate of Australia in its relation to agriculture. Some of the more important facts brought out in Dr. Taylor's paper are herewith briefly summarized.

Australia has a lower average elevation than any other continent and is characterized by a greatly diversified climate. Rainfall is the chief factor governing settlement and agriculture and varies from 40 to 50 inches or more in limited areas along the northern, eastern, and southern coasts, to less than 10 inches throughout much of the interior of the country. Generally speaking, there are four major rainfall regions—summer rains in the north, or the tropical portions of the continent, winter rains in the south, a rather uniform rain region in the east, and an arid region in the interior and middle west.

In more than one-third of the continent drought is a permanent condition, while one-half of it receives practically no rain for six months of the year. It is the border land between the arid region and moist districts, where damaging drought is frequent and much feared, for here lies the main wheat belt. As regards the inland portion of South Australia, drought occurs about once in three years. Considerable attention has been given to irrigation. It is difficult to determine the lowest limits of rainfall which admit of profitable agriculture in Australia without irrigation. In much of the wheat belt only one-third of the area is under wheat at a time; the dry farming methods of fallowing and careful tilth are practiced and become increasingly important as the arid area is approached.

The definition of dry farming varies in different sections. In South Australia, a region receiving less than 18 inches of rainfall a year, is classed as dry, while in New South Wales, a region receiving even 25 inches, is so classed. An important factor in this connection is evaporation; it has been stated that every 3 inches of evaporation requires 1 inch of rain additional as an offset, so that 15 inches of rain in the southwest of New South Wales is equivalent to 20 inches in the northwest portion.

Wheat is by far the most important crop in Australia. It is grown principally on the southern plains between the Blue Mountains and the interior desert, along a narrow belt in the comparatively moist, cool portions of the country. Its climatic limitations are indicated by the absence of the crop in the northern tropical portions and also in the moister coastal belt of the southeast. The primary climatic control is rainfall, but it is not the annual total so much as the seasonal distribution. For good yield it is essential that sufficient moisture be received in the early autumn (April–May), when plowing and seeding are in progress, and again in the spring (September–October), when the plants are heading and flowering. With these requirements realized, Australia is assured of a fine wheat crop.

In the early stages of wheat production in that country mistakes were made and corrective progress was slow. At first it was thought that abundant moisture was essential, and cultivation was confined to the wetter, coastal country, with its annual rainfall of 30 to 40 inches, but the results were disappointing. Later it was discovered that the drier, interior districts were more suitable for this plant, which altered the situation very happily. The bulk of the crop is now grown where the annual rainfall is less than 25 inches, and in some sections wheat is grown where rainfall is very light. It has been stated that on some well-worked, fallowed land good crops have been gathered when rainfall was less than 5 inches.

The next crop in importance is hay. In most countries hay consists chiefly of meadow and other grasses, but in Australia a very large proportion of it is comprised of wheat and oats. Crops originally sown for grain are frequently cut for hay owing to the fact that the outlook

[1] Vol. XLVI, pp. 331-355.

for grain is not satisfactory. For example, in the drought year of 1914 nearly 1,000,000 acres were cut for hay in New South Wales instead of the normal 150,000 acres.

The distribution of oats differs considerably from that of wheat, the chief producing region being found where the temperature is about 5° cooler than in the principal wheat districts and the rainfall 7 inches heavier. Sugar is confined to the well-watered east coast and is derived almost entireiy from cane. The temperature range under which sugar cane is grown is very considerable, varying from 68° to 78° F., but the necessity for a rainfall exceeding 40 inches confines production to the coast section.

The principal stock industry of this country is raising sheep, and here again rainfall is the control. Ninety per cent of the sheep of Australia are found in the southeastern third of the continent, and the number grazed in a region receiving less than 10 inches of rain is insignificant, while there are practically no sheep where the average temperature exceeds 77°. There is a close relation between the distribution of sheep and rainfall. With an annual fall of 8 inches, about 20 can be grazed per square mile; with 20 inches, 180 may be maintained; while with 35 inches, the number has increased to 400 per square mile. With rainfall greater than 35 inches, however, there is a rapid diminution in the number of sheep raised, and where 50 inches or more of rainfall are received no sheep are found. The cattle industry is of not nearly so great importance as that of raising sheep and in many of the cooler regions where sheep are raised cattle also graze, but as a rule the latter are found to thrive in the wetter localities.—*J. B. K.*

WEATHER AND THE YIELD OF TEA.

The influence of temperature, rainfall, and humidity on the yield of tea during 1918, 1919, and 1920 is discussed briefly by C. R. Harler in *Indian Tea Association Science Department Quarterly Journal*, 1921, No. 1, pp. 28–31.

A warm and moist atmosphere is essential for good-sized leaves. An abundant rainfall is necessary, although excessive rainfall causes a water-logged condition of the soil that reduces the leaf yield and weakens the plants.

The normal mean temperature during the hot weather in Assam is about 82.5° F., the normal relative humidity 94 per cent, and the rainfall 16 to 20 inches or more each month. A rise in temperature is usually accompanied by a lowered daytime humidity, which causes a slow development of the leaves. In the latter part of the summer of 1919 there was a considerable increase in temperature, while the relative humidity fell to 75 per cent. A fair amount of rain was received, but "the fall was mostly at night, so that its full effect in raising the humidity was lost." These conditions unfavorably affected the growth of the leaves.—*J. W. S.*

INCREASING LENGTH OF FROST-FREE PERIOD ON WISCONSIN CRANBERRY BOGS BY SANDING.

J. WARREN SMITH, Meteorologist.

While in charge of the Cranberry Experiment Station near Cranmoor, Wis., Mr. O. G. Malde made a very complete and extensive record of temperature on marsh soils. The period of observation was from 1906 to 1916, inclusive. In a recent statement of some of the results of a study of these records, Mr. Malde says:

> Temperature data recently compiled as a summary of 11 seasons of observations at the Cranberry Experiment Station (1906 to 1916, inclusive) show that there is an average of 58 days between the last spring and first fall frost (June 25 to August 22) over unsanded bog, as against 118 days between last spring and first fall frost over sanded bog. This represents a gain of 95 per cent in length of frost-free season on sanded bog over that on unsanded bog. The item of sanding, therefore, greatly reduces frost hazards and conserves the water supply by eliminating the need for the frequent flooding to protect against summer frosts. Sanding also permits and, in fact, requires deeper and better drainage, and is an insurance against fires on a bog in dry times. Sanding, together with thicker setting of plants, reduces labor and expense of weeding, besides insuring earlier cropping on the bog.

These statements are in harmony with the observations made by Prof. H. J. Cox of the Weather Bureau, as published in Bulletin T., U. S. Weather Bureau, "Frost and Temperature Conditions in the Cranberry Marshes of Wisconsin," published in 1910.

THE SEASONAL MARCH OF THE CLIMATIC CONDITIONS OF A GREENHOUSE, AS RELATED TO PLANT GROWTH.[1]

By EARL S. JOHNSTON.

[Author's abstract.[2]]

The study here reported was undertaken to measure and integrate the climatic conditions of a greenhouse by means of various measurements taken from standard plants, as these conditions varied throughout the year, and also to measure and integrate these same environmental conditions in terms of instrumental data, to prepare for an analysis of such an environmental complex and an interpretation of the plant values by means of the instrumental ones.

The general method employed by McLean was followed. Buckwheat plants (approximately alike at the start, when they were small seedlings) were grown for four-week exposure periods during a total time period of 13 months. A new period began every fortnight. The plants were grown in solution culture and the chemical surroundings of the roots were practically the same in all cases. Such culture plants are considered as integrating instruments for measuring the climatic conditions, as these effect plant processes. Measurements of stem height, dry weight, leaf area, and transpiration were made at regular intervals as "readings" of these "instruments." Simultaneous measurements of evaporation, radiation, and temperature were also obtained. These plant and instrumental measurements were made from two series of tests, one conducted under the ordinary conditions of an unshaded greenhouse at Baltimore, the other within a cheesecloth inclosure in the same greenhouse. Most of the measurements were recorded every week and weekly data are presented, but this paper deals mostly with the four-week data, and mainly with the exposed series.

The seasonal march of the four-week plant growth rates may be summarily described as follows: The rates for stem elongation, for dry-weight increase and for leaf-area increase had high summer values and low winter ones. These values increased during the spring and decreased during the autumn. The rates of transpirational water loss varied throughout the year in a similar manner, but they showed low values about the summer solstice. The rates of stem elongation also showed remarkably low values for a period about the time of the summer solstice. The approximate annual ranges (ratios of maximum to minimum) were as follows: Rate of stem elonga-

[1] Botanical contribution from the Johns Hopkins University No. 59. A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy, June, 1917.
Delay in publication has been brought about by the unsettled conditions existing during and immediately following the war.

[2] Reprinted from *Bulletin No. 245*, Univ. of Md. Agr. Exp. Sta.